

Cosmological Creation of Vector Bosons and Fermions

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Abstract

The cosmological creation of primordial vector bosons and fermions is described in the Standard Model of strong and electro-weak interactions given in a space-time with the relative standard of measurement of geometric intervals. Using the reparametrization - invariant perturbation theory and the holomorphic representation of quantized fields we derive equations for the Bogoliubov coefficients and distribution functions of created particles. The main result is the intensive cosmological creation of longitudinal Z and W bosons (due to their mass singularity) by the universe in the rigid state. We introduce the hypothesis that the decay of the primordially created vector bosons is the origin of the Cosmic Microwave Background radiation.

1. Introduction

It was the main achievement of the Hot Big Bang Cosmology to predict the Cosmic Microwave Background (CMB) radiation as one of the observable relics witnessing the thermal history of the expanding universe. The discovery of the CMB has in turn disfavored alternative cosmologies like the conformal-invariant Hoyle-Narlikar type cosmology [1]. The latter has recently been generalized and successfully applied to a description of luminosity distances for high redshift supernovae [2] without the need for a Λ term thus solving one of the major problems of the Standard Cosmology [3]. In this Conformal Cosmology, the Hubble law is explained by the cosmic evolution of elementary particles masses. The question arises about the origin of the CMB in the context of the Conformal Cosmology. In the present work we consider the simplest scenario where the origin of the CMB is the primordial creation of longitudinal vector bosons which have a singular behavior of the integral of motion in the vicinity of the cosmological singularity [4, 5].

In this paper, we give a systematic description of the cosmological creation of massive vector bosons and fermions in the Standard Model of strong and electroweak interactions. Our consideration of this problem differs from other calculations [6, 7, 8, 9] by i) the conformal symmetry [10], ii) the reparametrization - invariance [11, 12], and iii) the holomorphic representation of quantized fields [13].

The conformal symmetry was introduced in the theory of gravitation by Weyl in 1918 [14], based on the fact that we can measure only a ratio of two intervals. However, the original Weyl theory of a *vector* field had the defect of an ambiguous physical time as marked by Einstein in his comments to Weyls work. The conformal invariant theory of gravitation with an unambiguous physical time has been considered in Ref. [10] on the basis of the conformal invariant theory of a massless *scalar* (dilaton) field [15] with a negative sign.

The dilaton theory of gravitation is mathematically equivalent to the Einstein theory, and all solutions of the one theory can be constructed from those of the other by conformal transformations. In particular, the homogeneous approximation in Einstein's theory corresponds to the lowest order of the reparametrization - invariant perturbation theory in the flat space-time in the conformal invariant theory, where the homogeneous dilaton field scales all masses including the Planck mass. The corresponding Conformal Cosmology [3] describes the cosmic evolution of all masses [1] with respect to the observable conformal time instead of the cosmic evolution of the scale factor in the Standard Cosmology.

The considered perturbation theory keeps the main symmetry of all metric gravitation theories- the invariance with respect to reparametrizations of the "coordinate time". Just this invariance leads to the energy constraint that connects the total energy of all fields in the universe with the energy of the dilaton and converts it into the evolution parameter of the history of the universe.

The content of the paper is the following. In Section 2, we formulate the conformal - invariant version of the Standard Model (SM) unified with the dilaton version of Einsteins General Relativity (GR) theory. Section 3 is devoted to the reparametrization - invariant perturbation theory as the basis of the Conformal Cosmology. In Section 4, we derive equations of the cosmological creation of vector bosons and fermions. In Section 5, we solve these equations for the early universe in the rigid state. We summarize the results of this work in the Resumè of Section 6 and give our conclusions in the final Section 7.

2. Conformal General Relativity

2.1. Conformal - invariant unified theory

We consider a version of the conformal-invariant unified theory of gravitational, electroweak and strong interactions as the Standard Model where the dimensional parameter in the Higgs potential is replaced by the dilaton field w the dynamics of which is described by the negative Penrose-Chernikov-Tagirov action. The corresponding action takes the form

$$W_C = \int d^4x \sqrt{-g} [\mathcal{L}_{\Phi,w} + \mathcal{L}_g + \mathcal{L}_l + \mathcal{L}_{l\Phi}], \quad (1)$$

where

$$\mathcal{L}_{\Phi,w} = \frac{|\Phi|^2 - w^2}{6} R - \partial_\mu w \partial^\mu w + D_\mu^- \Phi (D^{\mu,-} \Phi)^* - \lambda (|\Phi|^2 - y_h^2 w^2)^2 \quad (2)$$

is the Lagrangian of dilaton and Higgs fields with $D_\mu^- \Phi = (\partial_\mu - i g \frac{\tau_a}{2} A_\mu - \frac{i}{2} g' B_\mu) \Phi$, and

$$\Phi = \begin{pmatrix} \Phi_+ \\ \Phi_0 \end{pmatrix}; \quad (|\Phi|^2 = \Phi_+ \Phi_- + \Phi_0 \bar{\Phi}_0) . \quad (3)$$

The Lagrangians of the gauge fields is

$$\mathcal{L}_g = -\frac{1}{4} (\partial_\mu A_\nu^a - \partial_\nu A_\mu^a + g \varepsilon_{abc} A_\mu^b A_\nu^c)^2 - \frac{1}{4} (\partial_\mu B_\nu - \partial_\nu B_\mu)^2, \quad (4)$$

and the Lagrangian of leptons

$$L = \begin{pmatrix} \nu_{e,L} \\ e_L \end{pmatrix}; \quad e_R, \nu_{e,R}, \quad (5)$$

is given by

$$\mathcal{L}_l = \bar{L}\gamma^\mu \left(D^F - ig\frac{\tau_a}{2}A_\mu + \frac{i}{2}g'B_\mu \right) L + \bar{e}_R\gamma^\mu \left(D_\mu^F + ig'B_\mu \right) e_R + \bar{\nu}_R\gamma^\mu \partial_\mu \nu_R, \quad (6)$$

where D^F is the Fock derivative. The Lagrangian describing the masses of the leptons is

$$\mathcal{L}_{l\varphi} = -y_e \left(e_R \Phi^+ L + \bar{L} \Phi e_R \right) - y_\nu \left(\bar{\nu}_R \Phi_C^+ L + \bar{L} \Phi_C \nu_R \right), \quad \Phi_C = \tau_2 \Phi_C^+ = \begin{pmatrix} \bar{\Phi}_0 \\ -\Phi_- \end{pmatrix}, \quad (7)$$

which includes the possibility of a finite neutrino mass, y_f are dimensionless parameters.

This theory is invariant with respect to conformal transformations, and it is given in the Weyl space of similarity with the relative standard of the measurement of intervals given by the ratio of two intervals [14]

$$r = \frac{ds^2}{ds_{\text{scale}}^2}. \quad (8)$$

The space of similarity is the manifold of Riemannian spaces connected by the conformal transformations.

The ratio (8) in the geometry of similarity depends on nine components of the metric tensor, the relative standard measurement of intervals allows us to remove the scale variable $|^{(3)}g|$ from the metric tensor. Therefore, we use the conformal-invariant Lichnerowicz variables [17] and the measurable conformal-invariant space-time interval

$$(ds^L)^2 = g_{\mu\nu}^L dx^\mu dx^\nu, \quad g_{\mu\nu}^L = g_{\mu\nu} |^{(3)}g|^{-1/3}, \quad |^{(3)}g|^L = 1, \quad (9)$$

with the notation $f_n^L = f_n |^{(3)}g|^{n/6}$, where (n) is the conformal weight being equal to $(1, 3/2, 0, -2)$ for the scalar, spinor, vector, and tensor field respectively. The Lichnerowicz interval depends on nine components of the metric $g_{\mu\nu}^L$.

The formulation of GR in terms of the Lichnerowicz variables reveals that the equivalence principle is violated in a direct unification of GR and SM where the gravitational coupling constant and inertial masses of particles are formed by different fields, i.e. when the scale component of metric and the Higgs field are treated as independent scalar fields. A possible solution to this problem is given in the following subsection.

2.2. Conformal Higgs Mechanism

In the contrast to the direct unification of GR and SM, the principle of equivalence of inertial and gravitational masses is incorporated into the conformal invariant Higgs mechanism through the dilaton-Higgs mixing [16]

$$w = \phi ch\chi, \quad \Phi_i = \phi \mathbf{n}_i sh\chi, \quad (\mathbf{nn}^+ = 1). \quad (10)$$

The modulus of dilaton-Higgs mixing ϕ simultaneously forms the gravitational coupling constant and inertial masses of particles.

After applying the transformation (10) the Lagrangian in the action (1) takes the form

$$\mathcal{L}_C = -\frac{\phi^2}{6}R + \frac{\phi}{\sqrt{-g}}\partial_\mu \left(\sqrt{-g}\partial^\mu \phi \right) + \phi^2 \partial_\mu \chi \partial^\mu \chi + \bar{\mathcal{L}}_{SM}, \quad (11)$$

where $\bar{\mathcal{L}}_{SM}$ is the SM Lagrangian with the Higgs potential

$$\mathcal{L}_{Higgs} = -\lambda\phi^4 \left(sh^2\chi - y_h^2 ch^2\chi \right)^2. \quad (12)$$

The extrema of this potential with respect to χ can be found from the condition

$$\frac{\partial \mathcal{L}_{Higgs}}{\partial \chi} = -4\lambda\phi^4(1 - y_h^2)sh\chi ch\chi \left(sh^2\chi(1 - y_h)^2 - y_h^2 \right) = 0, \quad (13)$$

which leads to two solutions

$$\chi_1 = 0, \quad |sh\chi_2| = \frac{y_h}{\sqrt{1 - y_h^2}}. \quad (14)$$

The last solution corresponds to the spontaneous SU(2) symmetry breaking in the SM. The problem is to show that the present day value of the modulus of the dilaton-Higgs mixing $\phi(t_0, x) = \varphi_0$ far from heavy masses is equal to the Newton constant

$$\varphi_0 = M_{\text{Planck}} \sqrt{\frac{3}{8\pi}}. \quad (15)$$

This means, that

$$y_h = \frac{m_h}{\varphi_0} \sim 10^{-17}. \quad (16)$$

In terms of the notations $\varphi_0\chi = H$ and $\varphi_0 y_h = \bar{M}_h$ we obtain in the limit of the infinite Planck mass the renormalizable version of the SM with the Higgs potential

$$-\lambda(H^2 - \bar{M}_h^2)^2 + O\left(\frac{1}{M_{\text{Planck}}}\right). \quad (17)$$

On the other hand, if $\lambda = 0$, then the SU(2) breaking solution is $\chi = \text{const}$, and we obtain the Higgs free SM version [10].

In the following, we consider the problem of cosmological particle creation in the framework of the dilaton theory (1).

3. The Energy Constrained Perturbation Theory

3.1. Conformal Cosmology

The cosmological applications of conformal gravity are based on the perturbation theory [13] that begins from the homogeneous approximation for the dilaton and metrics

$$\phi^L(t, x) = \varphi(t), \quad [g_L^{00}(t, x)]^{-1/2} = N_0(t), \quad g_{ij}^L = \delta_{ij} + h_{ij}, \quad (18)$$

where the conformal - invariant interval reads

$$ds_0^2 = d\eta^2 - dx_i^2, \quad d\eta = N_0(t)dt. \quad (19)$$

We keep only independent local field variables which are determined by a complete set of initial values. All nonphysical variables (for which the initial values depend on other

data) are excluded by the local constraint. In particular, the local part of the dilaton is excluded by the local energy constraint, i.e. the equation for the metric component g_L^{00} , and is converted into the Newtonian interaction potential. The first step of the perturbation theory is to consider the independent "free" fields in the linear approximation of their equations of motion. The global part of the dilaton $\varphi(t)$ should be considered as independent variable as its two initial values (the field and its momentum) cannot be determined by the one energy constraint only [12]. The latter is the consequence of the invariance of the theory with respect to reparametrizations of the "coordinate time" $t \rightarrow \bar{t} = \bar{t}(t)$.

The substitution of the ansatz (19) into the action (1) leads to the action of free fields in terms of physical variables [5, 13]

$$W_0 = \int_{t_1}^{t_2} dt \left[\varphi \frac{d}{dt} \frac{\dot{\varphi}}{N_0} V_0 + N_0 L_0 \right] , \quad (20)$$

where V_0 is a finite spatial volume and

$$L_0 = \frac{1}{2} \int_{V_0} d^3x N_0 \left(\mathcal{L}_\chi + \mathcal{L}_{\text{vec}}^\perp + \mathcal{L}_{\text{vec}}^\parallel + \mathcal{L}_{\text{rad}} + \mathcal{L}_s + \mathcal{L}_h \right) , \quad (21)$$

is the total Lagrangian of free fields. In particular,

$$\mathcal{L}_\chi = \varphi^2 \left(\frac{\dot{\chi}_i^2}{N_0^2} + \chi_i \left[\vec{\partial}^2 - 4\lambda(y_h\varphi)^2 \right] \chi_i \right) \quad (22)$$

is the Lagrangian of the Higgs field and

$$\begin{aligned} \mathcal{L}_{\text{vec}}^\perp &= \frac{1}{2} \left(\frac{\dot{v}_i^{\perp 2}}{N_0^2} + v_i^\perp \left[\vec{\partial}^2 - (y_v\varphi)^2 \right] v_i^\perp \right) , \\ \mathcal{L}_{\text{vec}}^\parallel &= -\frac{1}{2} (y_v\varphi)^2 \left(\frac{\dot{v}_i^\parallel}{N_0} \frac{1}{\left[\vec{\partial}^2 - (y_v\varphi)^2 \right]} \frac{\dot{v}_i^\parallel}{N_0} + v_i^{\parallel 2} \right) \end{aligned} \quad (23)$$

are Lagrangians of the transversal ($\mathcal{L}_{\text{vec}}^\perp$) and longitudinal ($\mathcal{L}_{\text{vec}}^\parallel$) components of the W- and Z- bosons [4, 5]. The Lagrangian of the fermionic spinor fields is given by

$$\mathcal{L}_s = \bar{\psi} \left(-y_s\varphi - i\frac{\gamma_0}{N_0} \partial_0 + i\gamma_j \partial_j \right) \psi , \quad (24)$$

where the rôle of the masses is played by the homogeneous dilaton field φ multiplied by dimensionless constants $y_{v,s}$. \mathcal{L}_{rad} is the Lagrangian of massless fields (photons γ , neutrinos ν) with $y_\gamma = y_\nu = 0$, and

$$\mathcal{L}_h = \frac{\varphi^2}{24} \left(\frac{\dot{h}^2}{N_0^2} - (\partial_i h)^2 \right) \quad (25)$$

is the Lagrangian of gravitons as weak transverse excitations of spatial metric for which $h_{ii} = 0$; $\partial_j h_{ji} = 0$. The last two equations follow from the unit determinant of the three-dimensional metric (9) and from the momentum constraint [13].

To find the evolution of all fields with respect to the proper time η , we use the Hamiltonian form of the action (1) in the approximation (19)

$$W_0^E = \int_{t_1}^{t_2} dt \left(\left[\int_{V_0} d^3x \sum_f p_f \dot{f} \right] - \dot{\varphi} P_\varphi - N_0 \left[-\frac{P_\varphi^2}{4V_0} + H(\varphi, f, p_f) \right] \right), \quad (26)$$

where the Hamiltonian $H(\varphi, f, p_f)$ is a sum of the Hamiltonians of free fields, with f and denoting the field of particle species f and p_f its conjugate momentum.

The variation of the action with respect to the homogeneous lapse-function N_0 yields the energy constraint

$$\frac{\delta W_0}{\delta N_0} = 0 \Rightarrow \varphi'^2 = \frac{\bar{H}(\varphi)}{V_0} := \rho(\varphi), \quad (27)$$

where the prime denotes the derivative with respect to the conformal time η . The fact that the dilaton, which scales all the elementary particle masses, has a nonzero derivative entails the cosmic evolution of the size of atoms similar to the Hoyle-Narlikar cosmology [1, 3, 10]. The cosmic evolution of the dilaton leads to a rescaling of the energy levels of atoms and to the observed redshift z of atomic line spectra

$$z + 1 = \varphi(\eta_0)/\varphi(\eta_0 - d/c) \simeq 1 + (d/c)H_0,$$

of a star at the distance d from the Earth where $H_0 = (\log \varphi)'|_{\eta_0}$ is the conformal cosmology definition of the Hubble parameter. With these definitions, the present-day value of the dilaton $\varphi_0 = \varphi(\eta_0)$ can be determined from the present-day value of density parameter $\Omega_0 = \rho(\varphi_0)/\rho_c$, where $\rho_c = 3M_{\text{Planck}}^2 H_0^2/(8\pi)$,

$$\varphi_0 = \Omega_0^{-1/2} M_{\text{Planck}} \sqrt{\frac{3}{8\pi}}. \quad (28)$$

Thus, the energy constrained theory obeys the Freedmann equation of the cosmological evolution

$$\eta(\varphi_0, \varphi_I) = \pm \int_{\varphi_I}^{\varphi_0} \frac{d\varphi}{\sqrt{\rho(\varphi)}} \quad (29)$$

that connects the geometric interval with the dynamics of the dilaton as evolution parameter. In accordance with the Dirac quantization of relativistic constrained systems the geometric time (29) is always positive [12].

3.2. Holomorphic Representation of Quantized Fields

In order to determine the observational energy density (27) we have to diagonalize the Hamiltonian

$$\hat{H} = \sum_{\varsigma, J} \omega_\varsigma^J(\varphi) \hat{N}_\varsigma^J, \quad (30)$$

where $\varsigma = k, f, \sigma$ stands for momenta, species, and spins, respectively. \hat{N}_ς^J are the number operators for bosons ($J = B$) and fermions ($J = F$), given by

$$\hat{N}_\varsigma^B = \frac{1}{2}(a_\varsigma^+ a_\varsigma + a_\varsigma a_\varsigma^+), \quad (31)$$

$$\hat{N}_\varsigma^{(J=F)} = (a_\varsigma^+ a_\varsigma - d_\varsigma d_\varsigma^+). \quad (32)$$

We introduce the representation of particles as holomorphic field variables

$$f(t, \vec{x}) = \sum_k \frac{C_f(\varphi) \exp(ik_i x_i)}{V_0^{3/2} \sqrt{\omega_f(\varphi, k)}} \bar{f}_J(t, k) , \quad (33)$$

where

$$\bar{f}_B(t, k) = \frac{1}{\sqrt{2}} \sum_{\sigma} \left(a_{\sigma}^+(-k, t) \epsilon_{\sigma}(-k) + a_{\sigma}(k, t) \epsilon_{\sigma}(k) \right) , \quad (34)$$

$$\bar{f}_F(t, k) = \sum_{\sigma} \left(d_{\sigma}^+(-k, t) v^*(-k) + a_{\sigma}(k, t) u_{\sigma}(k) \right) , \quad (35)$$

and $\omega_f(\varphi, k) = \sqrt{k^2 + y_f^2 \varphi^2}$ are the one-particle energies for particle species $f = h, \gamma, v, s, \chi$ with the dimensionless mass parameters y_f and

$$C_h(\varphi) = \frac{\sqrt{12}}{\varphi}, \quad C_{\gamma}(\varphi) = C_s(\varphi) = 1, \quad C_v^{\perp} = 1, \quad C_v^{\parallel} = \frac{\omega_v}{y_v \varphi}, \quad C_{\chi}(\varphi) = \frac{\sqrt{2}}{\varphi}.$$

The coefficients $(C_h, C_v^{\parallel}, C_{\chi})$ exhibit the mass singularity of gravitons, longitudinal components of massive vector fields [5], and the Higgs fields. These mass singularities lead to the intensive cosmological creation of the corresponding particles that follows from the first terms of the action (26) when represented in terms of holomorphic variables

$$\left[\int_{V_0} d^3x \sum_f p_f \dot{f} \right]_B = \sum_{\varsigma} \frac{\imath}{2} (a_{\varsigma}^+ \dot{a}_{\varsigma} - a_{\varsigma} \dot{a}_{\varsigma}^+) - \sum_{\varsigma} \frac{\imath}{2} (a_{\varsigma}^+ a_{\varsigma}^+ - a_{\varsigma} a_{\varsigma}) \dot{\Delta}_{\varsigma}(\varphi), \quad (36)$$

$$\left[\int_{V_0} d^3x \sum_f p_f \dot{f} \right]_F = \sum_{\varsigma} \imath (d_{\varsigma} \dot{d}_{\varsigma}^+ + a_{\varsigma}^+ \dot{a}_{\varsigma}) + \sum_{\varsigma} \imath (a_{\varsigma}^+ d_{\varsigma}^+ - d_{\varsigma} a_{\varsigma}) \dot{\Delta}_{\varsigma}(\varphi) . \quad (37)$$

$\Delta_{\varsigma}(\varphi)$ are terms responsible for particle creation,

$$\Delta_h(\varphi) = \ln(\varphi) - \ln(\varphi_I) , \quad (38)$$

$$\Delta_v^{\perp}(\varphi) = \ln(\sqrt{\omega_v}) - \ln(\sqrt{\omega_I}) , \quad (39)$$

$$\Delta_v^{\parallel}(\varphi) = \Delta_h(\varphi) - \Delta_v^{\perp}(\varphi) , \quad (40)$$

$$\Delta_{\chi}(\varphi) = \Delta_h(\varphi) + \Delta_v^{\perp}(\varphi) , \quad (41)$$

$$\Delta_s(\varphi) = \sigma \left[\arctan\left(\frac{y_s \varphi}{k}\right) - \arctan\left(\frac{y_s \varphi_I}{k}\right) \right] , \quad \sigma = \pm \frac{1}{2} , \quad (42)$$

where φ_I and ω_I are initial data.

4. Cosmological Pair Creation

4.1. Bogoliubov Quasiparticles

The local equations of motion for the system (26) can be written as [13]

$$-\imath \frac{d}{d\eta} \chi_{\varsigma} = -\imath \chi'_{\varsigma} = \hat{H}_{\varsigma}(\varphi) \chi_{\varsigma} , \quad (43)$$

where

$$\hat{H}_\varsigma = \begin{pmatrix} \omega_\varsigma, & -\imath\Delta'_\varsigma \\ -\imath\Delta'_\varsigma, & -\omega_\varsigma \end{pmatrix}, \quad \chi_\varsigma^{(B)} = \begin{pmatrix} a_\varsigma^+ \\ a_\varsigma \end{pmatrix}, \quad \chi_\varsigma^{(F)} = \begin{pmatrix} d_\varsigma^+ \\ a_\varsigma \end{pmatrix}, \quad (44)$$

for bosons (B) and fermions (F), respectively. Exact solutions of these equations of motion were obtained by their diagonalization with the Bogoliubov transformations [13]

$$\chi_\varsigma = \hat{O}_\varsigma \psi_\varsigma, \quad \Rightarrow \quad -\imath\psi'_\varsigma = [\imath\hat{O}_\varsigma^{-1}\hat{O}'_\varsigma + \hat{O}_\varsigma^{-1}\hat{H}_\varsigma\hat{O}_\varsigma] \psi_\varsigma \equiv \bar{H}_\varsigma \psi_\varsigma, \quad (45)$$

where \bar{H}_ς is required to be diagonal

$$\bar{H}_\varsigma = \begin{pmatrix} \bar{\omega}_\varsigma, & 0 \\ 0, & -\bar{\omega}_\varsigma \end{pmatrix}; \quad \det \hat{O}_\varsigma = 1; \quad \psi_\varsigma^{(F)} = \begin{pmatrix} b_\varsigma^+ \\ c_\varsigma \end{pmatrix}, \quad \psi_\varsigma^{(B)} = \begin{pmatrix} b_\varsigma^+ \\ b_\varsigma \end{pmatrix}. \quad (46)$$

The Bogoliubov parametrizations for the coefficients are

$$\begin{aligned} b_\varsigma^+ &= \cos(r_\varsigma)e^{-i\theta_\varsigma}d_\varsigma^+ + \imath\sin(r_\varsigma)e^{i\theta_\varsigma}a_\varsigma, \\ c_\varsigma &= \cos(r_\varsigma)e^{i\theta_\varsigma}a_\varsigma + \imath\sin(r_\varsigma)e^{-i\theta_\varsigma}d_\varsigma^+, \end{aligned} \quad (47)$$

and the Hermitian conjugate for fermions, and

$$\begin{aligned} b_\varsigma^+ &= \cosh(r_\varsigma)e^{-i\theta_\varsigma}a_\varsigma^+ - \imath\sinh(r_\varsigma)e^{i\theta_\varsigma}a_\varsigma, \\ b_\varsigma &= \cosh(r_\varsigma)e^{i\theta_\varsigma}a_\varsigma + \imath\sinh(r_\varsigma)e^{-i\theta_\varsigma}a_\varsigma^+ \end{aligned} \quad (48)$$

for bosons. For each ς we get two equations for the two unknown functions $r_\varsigma, \theta_\varsigma$

$$\begin{aligned} [\omega_\varsigma - \theta'_\varsigma] \sinh(2r_\varsigma) &= \Delta'_\varsigma \cos(2\theta_\varsigma) \cosh(2r_\varsigma), \\ r'_\varsigma &= -\Delta'_\varsigma \sin(2\theta_\varsigma) \end{aligned} \quad (49)$$

for bosons, and

$$\begin{aligned} [\omega_\varsigma - \theta'_\varsigma] \sin(2r_\varsigma) &= \Delta'_\varsigma \cos(2\theta_\varsigma) \cos(2r_\varsigma), \\ r'_\varsigma &= -\Delta'_\varsigma \sin(2\theta_\varsigma) \end{aligned} \quad (50)$$

for fermions.

The diagonalization procedure has two immediate consequences: (i) integrals of motion of the type of numbers of the Bogoliubov quasiparticles are obtained and (ii) the possibility to choose the initial states as corresponding to the vacuum of the Bogoliubov quasiparticles (the well-known *squeezed vacuum* [13])

$$b_\varsigma|0 >_{\text{sq}} = 0. \quad (51)$$

In the case of the vacuum initial data (51), the Bogoliubov equations (49) are closed by Eq. (27) for evolution of the universe

$$\varphi'^2 = \frac{1}{V_0} \sum_\varsigma \omega_\varsigma(\varphi)_{\text{sq}} < 0 | \hat{N}_\varsigma | 0 >_{\text{sq}} = \rho(\varphi). \quad (52)$$

The number of particles created during the time η is

$$\mathcal{N}_\zeta^{(B)}(\eta) = {}_{\text{sq}} \langle 0 | \hat{N}_\zeta^{(B)} | 0 \rangle_{\text{sq}} - \frac{1}{2} = \sinh^2 r_\zeta(\eta) \quad (53)$$

for bosons, and

$$\mathcal{N}_\zeta^{(F)}(\eta) = {}_{\text{sq}} \langle 0 | \hat{N}_\zeta^{(F)} | 0 \rangle_{\text{sq}} + \frac{1}{2} = \sin^2 r_\zeta(\eta) \quad (54)$$

for fermions respectively.

4.2. The redshift representation

To compare with the present-day cosmological data ρ_0 and φ_0 , it is useful to rewrite the Bogoliubov equations (49) in terms of the redshift z and the density parameter $\Omega(z)$ defined as

$$z + 1 = \frac{\varphi_0}{\varphi}, \quad \Omega(z) = \frac{\rho}{\rho_c}. \quad (55)$$

Then Eq. (52) for the evolution of the universe takes the form (we take $\Omega_0 = 1$ from now on)

$$H(z) := \frac{\varphi'}{\varphi} = -\frac{z'}{z+1} = (z+1)\sqrt{\Omega(z)}H_0, \quad (56)$$

where $H_0 = \varphi'_0/\varphi_0$ is a value of the present-day Hubble parameter. All equations can be rewritten in the terms of z -factor, in particular, the Bogoliubov equations (49) for bosons become

$$\begin{aligned} \sinh(2r_\zeta) \left[\frac{\omega_\zeta}{z'} - \frac{d}{dz} \theta_\zeta \right] &= \cos(2\theta_\zeta) \cosh(2r_\zeta) \frac{d}{dz} \Delta_\zeta, \\ \frac{d}{dz} r_\zeta &= -\sin(2\theta_\zeta) \frac{d}{dz} \Delta_\zeta, \end{aligned} \quad (57)$$

where z' is determined by eq. (56).

4.3. The vacuum initial values

In the case of the early universe, we have a large current Hubble parameter (56) or small one-particle energies $\Delta' \ll \omega$. To analyze the Bogoliubov equations (49) in this case, we change variables $(r, \theta \rightarrow C, \mathcal{N})$

$$\begin{aligned} \cos(2\theta_\zeta) \sinh(2r_\zeta) &= C_\zeta, \\ \sinh(2r_\zeta) &= \sqrt{\mathcal{N}(\mathcal{N}+1)}. \end{aligned} \quad (58)$$

Then, equations (49) take the form

$$\begin{aligned} \mathcal{N}'_\zeta &= \left(\frac{\Delta'_\zeta}{2\omega_\zeta} \right) C'_\zeta, \\ \mathcal{N}'_\zeta &= -\Delta'_\zeta \sqrt{4\mathcal{N}_\zeta(\mathcal{N}_\zeta+1) - C_\zeta^2}. \end{aligned} \quad (59)$$

In the limit of the early universe ($\Delta' \ll \omega$), Eqs. (59) reduce to

$$\begin{aligned} C'_\varsigma &= 0, \\ \frac{d\mathcal{N}_\varsigma}{d\Delta_\varsigma} &= -\sqrt{4\mathcal{N}_\varsigma(\mathcal{N}_\varsigma + 1) - C_\varsigma^2}. \end{aligned} \quad (60)$$

A general solution of these equations is

$$\begin{aligned} 2\mathcal{N}_\varsigma + 1 \equiv \cosh(2r_\varsigma) &= \cosh(2\Delta_\varsigma) + \frac{C_\varsigma^2}{2}e^{-2\Delta_\varsigma}, \\ C_\varsigma &= \text{const}. \end{aligned} \quad (61)$$

From equations (61) it follows that the *vacuum* initial state (51) $\mathcal{N}_\varsigma(\eta = 0) = 0$ entails that $C_\varsigma(\eta = 0) = 0$. In terms of r and θ this corresponds to the initial values for the cosmic evolution

$$r_\varsigma(\eta = 0) = 0, \quad \theta_\varsigma(\eta = 0) = \frac{\pi}{4}. \quad (62)$$

The solution (61) to eq. (60) for $\omega = 0$ can be treated as the Goldstone mode that rejects the symmetry breaking with respect to translations in time. The numbers of created particles for the large Hubble limit are determined by the vacuum solutions

$$r_\varsigma = \Delta_\varsigma, \quad \theta_\varsigma = \frac{\pi}{4}. \quad (63)$$

In accordance with equations (53) and (54), we have

$$\mathcal{N}_\varsigma^{(B)} = \sinh^2 \Delta_\varsigma(\varphi), \quad \mathcal{N}_\varsigma^{(F)} = \sin^2 \Delta_\varsigma(\varphi). \quad (64)$$

In particular, the number of created fermions is equal to

$$\mathcal{N}_{s,k,\sigma} = \frac{1}{2} \left(1 - \frac{k^2 + y_s^2 \varphi \varphi_I}{\omega_s(\varphi) \omega_s(\varphi_I)} \right). \quad (65)$$

It is easy to see that the relativistic limit of large momenta prevents the cosmological creation of all particle species except for gravitons and longitudinal bosons in accordance with their mass singularity [5, 4].

5. Early Universe Scenario

5.1. Rigid state

From the action (1) considered in this work one can see that at the beginning of time $\eta \sim 0$, the dilaton goes to zero $\varphi \sim 0$ together with the potential energy, whereas the kinetic energy of gravitons goes to infinity as $\sim 1/\varphi^2$, $\mathcal{N}_h \sim 1/\varphi^2$. This behavior is well known [18] from anisotropic homogeneous excitations of the metrics in a universe with the rigid equation of state (the Kasner stage). This corresponds to the behavior of the conformal density (55)

$$\Omega(z) = \Omega_{\text{Rigid}}(z + 1)^2, \quad \Omega_{\text{Rigid}} \leq 1, \quad (66)$$

and the evolution of the universe (56)

$$H(z) := \frac{\varphi'}{\varphi} = -\frac{z'}{z+1} = (z+1)^2 \sqrt{\Omega_{\text{Rigid}}} H_0 . \quad (67)$$

The solution of this equation takes the form

$$\varphi^2(\eta) = \frac{\varphi_0^2}{(z+1)^2} = \varphi_I^2 \left[\frac{\eta + \eta_I}{\eta_I} \right] , \quad (68)$$

where the subscript “I” denotes values at the initial time η_I . For definiteness, we list the values of the initial Hubble parameter H_I , initial time η_I , initial z-factor $(z_I + 1)$, and initial vector boson mass $m_v(z_I)$

$$H_I = H(z_I) = \frac{1}{2\eta_I} = (z_I + 1)^2 H_0 \sqrt{\Omega_{\text{Rigid}}} , \quad z_I + 1 = \frac{\varphi_0}{\varphi_I} , \quad m_v(z_I) = \frac{m_v}{z_I + 1} . \quad (69)$$

To isolate the point of singularity, we shall consider the beginning of time $\eta = 0$ in Eq. (68) with the initial value φ_I for dilaton as the beginning of the creation of the primordial vector bosons.

In the anisotropic era, the Bogoliubov equations (49) for the numbers of created vector bosons (longitudinal ($||$), and transversal (\perp)) can be rewritten in terms of dimensionless variables for time and momentum

$$\tau = \eta/\eta_I, \quad x = \frac{q}{m_v(z_I)} , \quad (70)$$

and the vector boson dispersion relation

$$\omega_v = H_I \gamma_v \sqrt{1 + \tau + x^2} , \quad (71)$$

where $\gamma_v = \frac{m_v(z_I)}{H_I}$ is the vector boson mass parameter. The corresponding Bogoliubov equations (49) for the number of created bosons in the anisotropic (rigid state) era are defined by the functions

$$\Delta'_\perp = \frac{1}{2} \frac{\omega'_v}{\omega_v} = H_I \frac{1}{2(1 + \tau + x^2)} , \quad (72)$$

$$\Delta'_\parallel = \frac{\varphi'}{\varphi} - \Delta'_\perp = H_I \left[\frac{1}{1 + \tau} - \frac{1}{2(1 + \tau + x^2)} \right] . \quad (73)$$

The initial values are given by (62), see also Appendix A. The form of these equations shows us that the parameter value $\gamma_v = 1$ is distinguished. For $\Omega_{\text{Rigid}} = 1$ this value corresponds to $z_I + 1 = (m_v/H_0)^{1/3} \sim 3.4 \times 10^{14}$. At this high redshift $H_I = m_v(z_I) = k_B 2.76$ K, i.e. the dilaton field changed so rapidly as to create vector mesons which were light enough in that era to form upon annihilation the CMB the temperature of which is an invariant of the cosmic evolution. In the following we study the cosmological creation of vector bosons for the universe in the rigid state.

5.2. Creation of vector bosons by the anisotropic universe

We have calculated the number of created bosons during their lifetime $\tau_L = \eta_L/\eta_I$. To estimate roughly this time η_L , we use the lifetime of W-bosons in the Standard Model at this moment

$$\eta_L + \eta_I = \frac{\sin^2 \theta_W}{m_W(z_L)\alpha_{QED}} ,$$

where θ_W is the Weinberg angle, $\alpha_{QED} = 1/137$, and z_L is the z-factor at this time. Using Eqs. (68), (69)), and the equality $\eta_I m_W(z_L) = (\gamma_v/2)(z_I + 1)/(z_L + 1)$, we rewrite the previous equation in terms of the z-factor

$$\tau_L + 1 = \frac{(z_I + 1)^2}{(z_L + 1)^2} = \frac{(z_L + 1)}{(z_I + 1)} \frac{2 \sin^2 \theta_W}{\gamma_v \alpha_{QED}} , \quad (74)$$

The solution of this equation (74) is

$$\tau_L + 1 = \left(\frac{2 \sin^2 \theta_W}{\gamma_v \alpha_{QED}} \right)^{2/3} \simeq \frac{16}{\gamma_v^{2/3}} , \quad (75)$$

and for the timelife of created bosons we have

$$\tau_L = \frac{\eta_L}{\eta_I} \simeq \frac{16}{\gamma_v^{2/3}} - 1 . \quad (76)$$

In the following we consider the case $\gamma_v = 1$ for which $\tau_L = 15$.

The numerical solutions of the Bogoliubov equations (49) for the time dependence of the vector boson distribution functions \mathcal{N}^{\parallel} and \mathcal{N}^{\perp} are given in Fig. 1 (left panels) for the momentum $x = 1.25$. We can see that the longitudinal function is greater than the transversal one.

The momentum dependence of these functions at the time $\tau = 14$ is given on the right panels of Fig.1. Upper panel shows us the intensive cosmological creation of the longitudinal bosons in comparison with the transversal ones. This fact is in agreement with the mass singularity of the longitudinal vector bosons discussed in Refs. [4, 5].

One of the features of this intensive creation is a high momentum tail of the momentum distribution of longitudinal bosons which leads to a divergence of the density of created particles defined as [7]

$$n_v(\eta_L) = \frac{1}{2\pi^2} \int_0^\infty dq q^2 \left[\mathcal{N}^{\parallel}(q, \eta_L) + 2\mathcal{N}^{\perp}(x, \eta_L) \right] . \quad (77)$$

The divergence is a defect of our approximation, where we neglected all interactions of vector bosons, that form the collision integral in the kinetic equation for the distribution functions.

In order to obtain a finite result for the density we suggest to multiply the primordial distributions $\mathcal{N}^{\parallel}(x, \eta_L)$ and $\mathcal{N}^{\perp}(x, \eta_L)$ with the Bose - Einstein distribution ($k_B = 1$)

$$\mathcal{F} \left(\frac{q}{T}, \frac{m_v(\tau)}{T}, \frac{\mu(\tau)}{T} \right) = \left\{ \exp \left[\frac{\omega_v(\tau) - \mu(\tau)}{T} \right] - 1 \right\}^{-1} , \quad (78)$$

where T is considered as the regularization parameter. Then, the density is given as

$$n_v(T, \eta_L) = \frac{T^3}{2\pi^2} \int_0^\infty dy y^2 \mathcal{F}(y, \gamma_T, \gamma_\mu) \left[\mathcal{N}^\parallel \left(\frac{y}{\gamma_T}, \eta_L \right) + 2\mathcal{N}^\perp \left(\frac{y}{\gamma_T}, \eta_L \right) \right] \quad (79)$$

for each vector boson ($v = W^\pm, Z^0$), where

$$\gamma_T = \frac{m_v(z_I)}{T}, \quad \gamma_\mu = \frac{\mu(z_I)}{T}. \quad (80)$$

The problem is to find the value of this density.

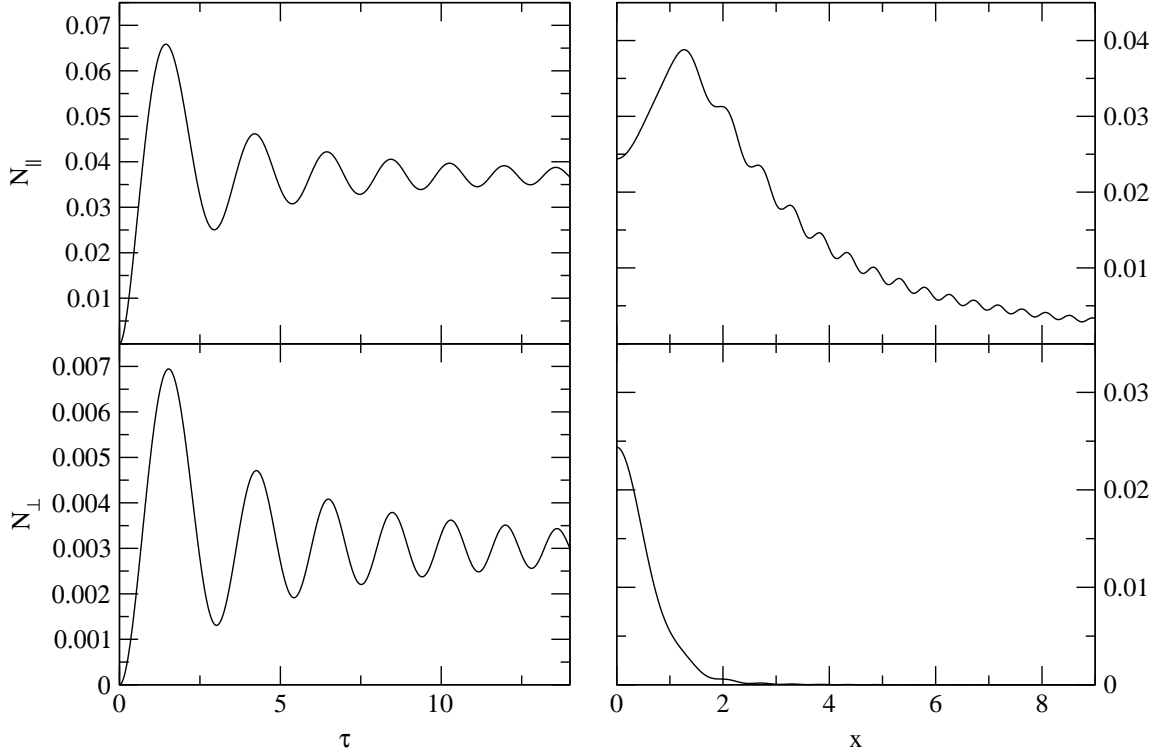


Figure 1: Time dependence for the dimensionless momentum $x = 1.25$ (left panels) and momentum dependence at the dimensionless time $\tau = \tau_L = 14$ (right panels) of the transverse (lower panels) and longitudinal (upper panels) components of the vector boson distribution function.

Our calculation presented on Fig.1 signals that the density (79) is established very quickly in comparison with the lifetime of bosons, and in the equilibrium there is a weak dependence of the density on the time (or z -factor). This means that the initial Hubble parameter H_I almost coincides with Hubble parameter at the point of the saturation H_s .

For example we calculated the values of integrals (77) for the regularization parameter

$$T = m_v(z_I) = H_I. \quad (81)$$

This choice corresponds to $\gamma_v = \gamma_T = 1, \mu = m_v$. The result of the calculation is

$$\frac{n_v}{T^3} = \frac{1}{2\pi^2} \left\{ [1.877]^\parallel + 2[0.277]^\perp = 2.432 \right\} , \quad (82)$$

where we denote the contributions of the longitudinal and transverse bosons by the labels (\parallel, \perp).

After the time τ_L primordial bosons decay. The final product of the decay of the primordial bosons includes photons. If one photon goes from the annihilation of the products of decay of W^\pm bosons, and another photon - from Z bosons, we can expect the density of photons in the Conformal Cosmology with the constant temperature and a static universe [3]

$$\frac{n_\gamma}{T^3} = \frac{1}{\pi^2} \{2.432\} . \quad (83)$$

By the comparison of this value with the present-day density of the cosmic microwave radiation

$$\frac{n_\gamma^{\text{obs}}}{T_{\text{CMB}}^3} = \frac{1}{\pi^2} \{2\zeta(3) = 2.402\} . \quad (84)$$

we can estimate the regularization parameter T . One can see that this parameter is the order of the temperature of the cosmic microwave background

$$T = T_{\text{CMB}} = 2.73 \text{ K} . \quad (85)$$

We can speak about thermal equilibrium for the primordial bosons with a temperature T_{eq} , if the inverse relaxation time [19]

$$\eta_{\text{rel}}^{-1}(z_I) = \sigma_{\text{scat}} n_v(T_{\text{eq}}) \quad (86)$$

where the scattering cross-section of bosons in the considered region is proportional to the inverse of their squared mass

$$\sigma_{\text{scat}} = \frac{\gamma_{\text{scat}}}{m_v^2(z)} \quad (87)$$

is greater than the primordial Hubble parameter H_I . This means that the thermal equilibrium will be maintained

$$\gamma_{\text{scat}} n_v(T_{\text{eq}}) = \frac{2.4}{\pi^2} \gamma_{\text{scat}} T_{\text{eq}}^3 = H(z_I) m_v^2(z_I) = H(0) m_v^2(0). \quad (88)$$

The right hand side of this formula is an integral of motion for the evolution of the universe in the rigid state. The estimation of this integral from the present values of the Hubble parameter and boson mass gives the value

$$\left[m_W^2(z_I) H(z_I) \right]^{1/3} = \left[m_W^2(0) H_0 \right]^{1/3} = 2.76 \text{ K} . \quad (89)$$

Thus we conclude that the assumption of a quickly established thermal equilibrium in the primordial vector boson system may be justified since $T \sim T_{\text{eq}}$. The temperature of the photon background emerging after annihilation and decay processes of W^\pm and Z bosons is invariant in the Conformal Cosmology and the simple estimate performed above gives a value surprisingly close to that of the observed CMB radiation.

A more detailed investigation of the kinetic processes which govern the transition from the primordial vector boson era to the photon era can be based on a solution of the corresponding kinetic equations [20] and will be given elsewhere.

5.3. The baryon asymmetry

The baryon asymmetry of the universe appears as a result of the polarization of the Dirac vacuum of quarks by transversal bosons in accordance with the selection rule of the Standard Model [21]

$$\Delta L = \Delta B = \Delta n_w + \Delta n_z , \quad (90)$$

where

$$\Delta n_W = \frac{4\alpha_{QED}}{\sin^2 \theta_W} J^W, \quad J^W = \int_0^{\eta^W} d\eta \int \frac{d^3x}{4\pi} \quad {}_{\text{sq}} \langle 0 | E_i^W B_i^W | 0 \rangle_{\text{sq}} , \quad (91)$$

$$\Delta n_Z = \frac{\alpha_{QED}}{\sin^2 \theta_W \cos^2 \theta_W} J^Z, \quad J^Z = \int_0^{\eta^Z} d\eta \int \frac{d^3x}{4\pi} \quad {}_{\text{sq}} \langle 0 | E_i^Z B_i^Z | 0 \rangle_{\text{sq}} \quad (92)$$

are the topological winding number functionals of the primordial W^\pm and Z bosons, and E_i, B_i are the electric and magnetic field strengths. The squeezed vacuum gives a nonzero value for these quantities

$$\int \frac{d^3x}{4\pi} \quad {}_{\text{sq}} \langle 0 | E_i^v B_i^v | 0 \rangle_{\text{sq}} = -\frac{V_0}{2} \int_0^\infty dk |k|^3 C_v(\eta, k) , \quad (93)$$

where $C_v(\eta, k)$ is given by the equation (58) for the transversal bosons. We estimated $J^W/V_0 T^3 \approx 1.44$ and $J^Z/V_0 T^3 \approx 2.41$ for $\gamma_v = 1$ and a timelife of the bosons $\tau_L^W \approx 15$, $\tau_L^Z \approx 30$, using the T-regularization (78).

Thus, we can see that the baryon asymmetry can be explained by the topological winding number functional of the primordial bosons and the superweak interaction of d and s -quarks ($d + s \rightarrow s + d$) with CP-violation, experimentally observed in the decays of K mesons [22]. A more detailed consideration of the baryon asymmetry phenomenon will be presented in a subsequent paper.

6. Résumé

We have considered the simplest Cold Universe Scenario where the physical reason of CMB is the cosmic creation of primordial longitudinal vector bosons. Among the matter fields there is only one longitudinal component of the vector bosons with a singular behavior of the integral of motion at this region. To see this singularity, we consider only the mass term for the time component v_0 that is proportional to the time derivative of the longitudinal component (due to the constraint $v_0 \sim \dot{v}_\parallel$). The toy Lagrangian of the conformal universe filled in these bosons takes the form

$$\mathcal{L} = \mathcal{L}_\varphi + \mathcal{L}_\parallel = - \left(\frac{d\varphi}{d\eta} \right)^2 + \varphi^2(\eta) \left(\frac{dv_\parallel}{d\eta} \right)^2 \quad (94)$$

with the equations of motion

$$\frac{d^2(\varphi)}{d\eta^2} + 2\varphi \left(\frac{dv_\parallel}{d\eta} \right)^2 = 0 , \quad (95)$$

$$\frac{d}{d\eta} \left[\varphi^2(\eta) \frac{dv_\parallel}{d\eta} \right] = 0 . \quad (96)$$

The last equation entails the existence of an integral of motion

$$\left[\varphi^2(\eta) \frac{dv_{||}}{d\eta} \right] = P_v. \quad (97)$$

In terms of this integral of motion the Lagrangian (94) and the energy of matter takes the form of the rigid state

$$\mathcal{L}_{||} = \frac{P_v^2}{\varphi^2(\eta)}, \quad (98)$$

whereas the equation of motion for the dilaton (95) becomes trivial for the square of the dilaton

$$\frac{d^2(\varphi^2)}{d\eta^2} = 0. \quad (99)$$

A solution of this classical equation is defined by an initial position φ_I and velocity H_I of the dilaton

$$\varphi^2(\eta) = \varphi_I^2(1 + 2H_I\eta) \quad (100)$$

H_I coincides with the initial Hubble parameter φ'_I/φ_I .

The numerical solution of the exact Bogoliubov equations shows us that the temperature equilibrium is established so quickly that the z-factor and the Hubble parameter almost do not change. The latter determine the temperature of the primordial bosons as the integral of motion

$$T_{\text{eq}} = [H_0 m_W^2(0)]^{1/3} = 2.76 \text{ K}, \quad (101)$$

which almost coincides with the present-day value of the cosmic microwave radiation.

Thus, in the context of the relative standard of measurements and the Conformal Cosmology, the estimations of temperature and density of the primordial vector bosons show us that the origin of the cosmic microwave radiation and the observable matter in the universe can be seen in the decay of the primordial vector bosons into photons, leptons, and quarks. These primordial vector bosons are created by the conformal universe at the time $\eta_I = 10^{-12}$ that corresponds to the initial z-factor

$$z_I + 1 = \frac{m_W(0)^{1/3}}{H_0^{1/3}} \simeq 3.5 \times 10^{14}. \quad (102)$$

It is worth to emphasize that in the considered model of the Conformal Cosmology [3], the temperature (101) is a constant. In Conformal Cosmology, we have the mass history

$$m_{\text{era}}(z) = \frac{m_{\text{era}}(0)}{(1+z)} = T_{\text{eq}} \quad (103)$$

with the constant temperature $T_{\text{eq}} = 2.73 \text{ K} = 2.35 \times 10^{-13} \text{ GeV}$, where $m_{\text{era}}(0)$ is a characteristic energy (mass) of an era of the universe evolution.

Eq. (103) has the important consequence that all those physical processes which concern the chemical composition of the universe and which depend basically on Boltzmann factors with the argument (m/T) cannot distinguish between the Conformal Cosmology and the Standard Cosmology due to the relations

$$\frac{m(z)}{T(0)} = \frac{m(0)}{(1+z)T(0)} = \frac{m(0)}{T(z)}. \quad (104)$$

This formula makes transparent that in this order of approximation a z -history of masses with invariant temperatures in the rigid state of Conformal Cosmology is equivalent to a z -history of temperatures with invariant masses in the radiation stage of the Standard Cosmology. We expect therefore that the Conformal Cosmology allows us to keep the scenarios developed in the Standard Cosmology in the radiation stage for, e.g. the neutron-proton ratio and primordial element abundances.

Recall that the theoretical foundation of the radiation stage in the Standard Cosmology became problematic in the light of the new Supernova data on the present-day accelerating evolution of the universe at the dominance of the inflation stage. In this situation it is difficult to explain in the Standard Cosmology the status of the radiation stage that follows the primordial inflation stage and is followed by a short matter era which in turn is terminated by the present-day inflation stage. On the other hand, in the Conformal Cosmology a unique permanent rigid state can explain the primordial creation of matter from the vacuum, the primordial element abundances, and the recent acceleration witnessed by distant type Ia supernovae [2, 3].

An important new feature of the Conformal Cosmology relative to the Standard one is the absence of the Planck era, since the Planck mass is not a fundamental parameter but only the present-day value of the dilaton field [3, 10].

7. Conclusion

We have considered a unified theory of all interactions in a space-time with the Weyl relative standard of measurement. The laws of nature, i.e. the equations of motion, in this theory are conformal invariant and do not contain any dimensional parameter, whereas the initial data violate the conformal symmetry. We have shown that this unified theory leads to a conformal version of the Standard Cosmology which is free of those problems related to the expansion of the universe. In the Conformal Cosmology, instead of a z -history of the temperature we have obtained a z -history of masses at constant temperature where the number of created particles is determined by the initial data of the universe.

We have shown that the conformal symmetry, the reparametrization-invariant perturbation theory and the mass-singularity of the longitudinal components of vector bosons lead to the effect of an intensive creation of these bosons with the temperature $(m_W^2 H_0)^{1/3} \sim 2.73$ K and a density which resembles physical properties of the cosmic microwave background radiation. We have derived a similar enhancement of particle creation in the case of the Higgs field, but we do not consider this case in detail because its existence is not experimentally proven yet.

According to the scenario outlined in this work, the primordial boson radiation is created during a conformal time interval of 2×10^{-12} sec and subsequent annihilation and decay has formed all the matter in the universe.

The further z -history of the conformal universe repeats that of the Friedmann universe, with a remarkable difference : instead of the z -dependence of the temperature in an *expanding universe* with constant masses (Standard Cosmology), we have a z -history of masses in a *static universe* with almost constant temperature of the photon background in Conformal Cosmology.

The Conformal Cosmology provides definite solutions to the problems of Standard

Cosmology. The Minkowski flat space has no horizon problem. The problems of the Planck age also do not exist as the Planck mass is not a fundamental parameter of the theory but only the ordinary present-day value of the dilaton field.

In the present paper we have added to this appealing concept of Conformal Cosmology a physical mechanism explaining the origin of the matter content of the universe by pair creation of longitudinal vector bosons from the dilaton field which, in particular, gives a surprisingly good estimate for the temperature of the CMB radiation.

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Appendix A

The Bogoliubov equations for the Higgs field (χ) and vector bosons (v) in terms of dimensionless variables and parameters (70)-(72) take the form

$$\begin{aligned} \left[\frac{\gamma_v}{2} \sqrt{(1+\tau)y_\chi^2 + x^2} + \frac{d}{d\tau} \theta_\chi \right] \tanh(2r_\chi) &= \frac{1}{2} \left[\frac{1}{(1+\tau)y_\chi^2} + \frac{1}{2} \frac{1}{[(1+\tau)y_\chi^2 + x^2]} \right] \cos(2\theta_\chi) , \\ \frac{d}{d\tau} r_\chi &= -\frac{1}{2} \left[\frac{1}{(1+\tau)y_\chi^2} + \frac{1}{2} \frac{1}{[(1+\tau)y_\chi^2 + x^2]} \right] \sin(2\theta_\chi) , \\ \left[\frac{\gamma_v}{2} \sqrt{(1+\tau) + x^2} - \frac{d}{d\tau} \theta_v^\parallel \right] \tanh(2r_v^\parallel) &= \frac{1}{2} \left[\frac{1}{(1+\tau)} - \frac{1}{2} \frac{1}{[(1+\tau) + x^2]} \right] \cos(2\theta_v^\parallel) , \\ \frac{d}{d\tau} r_v^\parallel &= -\frac{1}{2} \left[\frac{1}{(1+\tau)} - \frac{1}{2} \frac{1}{[(1+\tau) + x^2]} \right] \sin(2\theta_v^\parallel) , \\ \left[\frac{\gamma_v}{2} \sqrt{(1+\tau) + x^2} - \frac{d}{d\tau} \theta_v^\perp \right] \tanh(2r_v^\perp) &= \frac{1}{4} \left[\frac{1}{(1+\tau) + x^2} \right] \cos(2\theta_v^\perp) , \\ \frac{d}{d\tau} r_v^\perp &= -\frac{1}{4} \left[\frac{1}{(1+\tau) + x^2} \right] \sin(2\theta_v^\perp) , \end{aligned}$$

where y_χ^2 is defined as

$$y_\chi^2 = 4\lambda \frac{y_h^2}{y_v^2} .$$

The creation of t-quarks with the mass

$$m_t = \frac{y_v}{y_s} m_W := \gamma_s m_W \quad (\gamma_s \simeq 2) ,$$

is described by r_t, θ_t with the equations

$$\left[\frac{\gamma_v}{2} \sqrt{\gamma_s^2(1+\tau) + x^2} - \frac{d}{d\tau} \theta_t \right] \sin(2r_t) = \frac{1}{4} \left[\frac{1}{(1+\tau) + x^2/\gamma_s^2} \right] \cos(2\theta_t) \cos(2r_t) ,$$

$$\frac{d}{d\tau}r_t = -\frac{1}{4} \left[\frac{1}{(1+\tau) + x^2/\gamma_s^2} \right] \sin(2\theta_t) ,$$

and the density

$$\frac{\langle n_t(\eta_L) \rangle}{T^3} = \frac{\Omega_A^{1/2} \gamma_v}{\pi^2} \int_0^\infty dx x^2 \mathcal{F}_t(x) \sin^2 r_t(\tau_L) ,$$

where

$$\mathcal{F}_t(x) = \left[\exp \left\{ \gamma_T (\sqrt{\gamma_s^2(1+\tau_L) + x^2} - \sqrt{\gamma_s^2(1+\tau_L)}) \right\} + 1 \right]^{-1} .$$

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